UNIVERSITY OF PENNSYLVANIA

ABSORPTION AND RESONANCE OF THE HELIUM INFRARED LINES

MENTZER RUSSELL WEHR

A THESIS

IN PHYSICS

PRESENTED TO THE FACULTY OF THE GRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

PHILADELPHIA

1932

ABSORPTION AND RESONANCE OF THE HELIUM INFRARED LINES

A THESIS

IN PHYSICS

PRESENTED TO THE FACULTY OF THE GRADUATE SCHOOL OF THE UNIVERSITY OF PENNSYLVANIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

MENTZER RUSSELL WEHR

Reprint from
The Physical Review, Vol. 39, No. 5

R. UNIV.
BIBLIOTHEEK
LEIDEN

PHILADELPHIA

1932

ABSORPTION AND RESONANCE OF THE HELIUM INFRARED LINES

By M. R. Wehr
Randal Morgan Laboratory of Physics, University of Pennsylvania

(Received January 18, 1932)

Abstract

The absorption of helium excited at low voltages for its own lines, the 2^3S-2^3P at 10830A and the 2^1S-2^1P at 20582A, is determined. The percentage absorption of the 2^3S-2^3P line increases when either the exciting current or the pressure in the absorbing tube is increased, and also when either the current or the pressure in the source tube is decreased. When the light to be absorbed is taken end on from a Geissler tube source, the percentage absorption is much less than when the light is taken off at right angles to the capillary. The changes with source tube conditions are ascribed to the corresponding variations of the shape and width of the emission line. Observable absorption begins when the exciting voltage is 25 volts. No absorption is detected at 19.8 volts, the excitation potential of the 2^3S state. The 10830A line shows strong resonance which is directly proportional to the percentage absorption. The absorption for the 20582A line is very small. It shows no detectable resonance.

Introduction

THE only radiations which helium atoms in the normal or unexcited state can absorb lie in the far ultraviolet corresponding to the removal of the electron directly from the $1S$ level of the atom. The absorption of unexcited helium[1] for its own radiation has been investigated. The absorption of helium when in the excited state, i.e., after the electron has been lifted from the $1S$ level, has also been studied. The radiations involved here lie in the visible[2,3,4] and infrared[5] regions. In all previous studies of the excited gas, the excitation has been secured by maintaining a high voltage discharge through it at 1000 volts or more.

Critical potential measurements have shown that the helium atom can be put into its first higher energy state by bombardment with electrons which have fallen through a potential difference of 19.77 volts. Specifically, the excitation function[6,7] of the 1^1S–2^3S state of helium shows that at a few tenths of a volt above this critical value, a number of atoms are already in the 2^3S state. In the investigation reported here, the absorption and resonance of helium for its own infrared lines, the 2^3S–2^3P at 10830A and the 2^1S–2^1P at 20582A, is measured while the excitation is maintained by a low voltage discharge. The potentials employed are close to the ionization potential. The infrared lines are particularly suitable for this work because: first, these lines

[1] Weatherby and Wolf, Phys. Rev. **29**, 135 (1927).
[2] McCurdy, Phil. Mag. **2**, 529 (1926).
[3] Takamine and Suga, Phil. Mag. **5**, 141 (1928).
[4] McLennan, Ruedy, and Allin, Proc. Roy. Soc. Can. **22** Sect. 3, 273 (1928).
[5] Paschen, Ann. d. Physik **45**, 625 (1914).
[6] Dymond, Proc. Roy. Soc. **107**, 291 (1924).
[7] Glockler, Phys. Rev. **33**, 175 (1929).

are by far the strongest in the spectrum; second, they are easily isolated by means of filters, thus avoiding the use of a spectrometer and consequent light loss; and third, previous work shows that they are highly absorbed.

Apparatus

The general arrangement of apparatus is shown in Fig. 1. The absorption tube A is of Pyrex and has plane windows at the ends. The field-free anode is a rectangular nickel box 9.6 cm long and 1.5 cm by 1.5 cm in cross section. Each end face has a slit 0.4 cm wide and 1 cm high in its center. The light to be absorbed passes through these slits lengthwise along the box. The gas inside the anode can be illuminated at right angles to its length through the nickel gauze which forms the one side. The bottom is also of gauze, and is insulated from the box so that the currents to each can be read separately when desired. The oxide-coated, equipotential cathode is a cylinder 11 cm

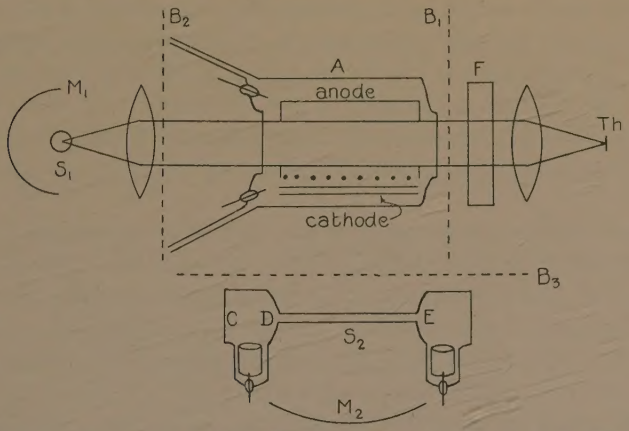

Fig. 1. Arrangement of apparatus. This diagram is not drawn to scale. The source S_2 and mirror M_2 are actually mounted at the same height as the center of the anode.

long, and is made of nickel tubing which has a 1.5 mil wall and is 80 mils in diameter. The cathode is heated internally by a 15 mil tungsten wire contained in a thin walled quartz tube. The coating material is prepared by mixing equal parts by weight of $SrCO_3$ and $BaCO_3$ in a little water. The cathode is 3 mm below the anode. Two strips of mica placed above the cathode and parallel to it, limit practically all of the excitation of the gas within the anode to the region in line with the slits. The tungsten leads are brought in through the stopper which is waxed in one end.

The sources, S_1 for the absorption measurements and S_2 for the resonance measurements, are Pyrex Geissler tubes which have an inside diameter of 3 mm. The capillary of the former is 5.5 cm long, and of the latter, 10 cm. The electrodes are of thin sheet molybdenum. This metal is more satisfactory than aluminum because of the ease with which it can be degassed. S_1 is mounted vertically, and S_2 horizontally. The large concave spherical mirror M_2 images S_2 along the line of the anode slits. The cylindrical mirror M_1 reflects in the direction of the absorbing column the light coming from the

back and sides of S_1, and thus increases the effective source intensity. By putting a mirror in the place of S_1, light taken end on from S_2 can be used for absorption measurements.

Two 350 volt airplane radio generators connected in series drive the sources. In order to have the light from S_1 of sufficiently constant intensity over the period of a reading, it is necessary that the voltage shall not vary by more than 1 part in 10000. Storage batteries floated across the generators maintain the necessary constancy.

The filter[8] for the isolation of the 10830A line consists of two Wratten and Wainwright gelatines, F29 and H45, mounted in *B* glass, and a 1 cm water cell. The filters form the sides of the cell. A sheet of biotite[9,10] 0.19 mm thick serves to isolate the 20582A line. The transmission curves of these filters were obtained with an infrared spectrometer and were found to agree with those given in the reference articles.

In the early stages of the work, an intensity measuring system which consisted of a Thalofide cell placed in one arm of a Wheatstone bridge[11] was employed. This arrangement is highly sensitive to light in the region 1μ. Unfortunately, the resistance changes of the Thalofide cells available for this work were not directly proportional to light intensity and there was no constant relation between these quantities. The cells also had a troublesome time lag.

The measuring instrument used in the final arrangement is a Burt compensated junction, vacuum thermocouple. A Leeds and Northrup *HS* galvanometer which has a resistance of 14 ohms is connected to the thermocouple. The resistance of the thermocouple is 35 ohms which is just slightly higher than the critical external damping resistance of the galvanometer. The actual distance from galvanometer to scale is 525 cm, but the effective distance is made twice as great by allowing the light beam reflected from the galvanometer mirror to fall on a stationary mirror outside the case from which it is reflected back to the galvanometer and from there to the scale. The scale can easily be read to 0.5 mm. A test of the galvanometer response shows that the deflections over the range of the scale, 50 cm, are directly proportional to the e.m.f. applied. The drift due to changes in room temperature is negligible —about 1 mm per hour.

Procedure

The system is evacuated in the usual way. The charcoal traps are heated at 350°C for a number of hours, and the metal parts degassed with an induction heater. When the pressure remains at less than 10^{-5} mm with the heaters on, the pumps are cut off, and the traps immersed in liquid air. About an hour later, helium which has been over charcoal at liquid air temperature, is allowed to flow into the system slowly. The purity of the gas is tested by observing the spectrum in both the source and absorption tubes when run at currents several times higher than the maxima used during observations. In

[8] Paschen, Ann. d. Physik **43**, 858 (1914).
[9] Konigsberger, Ann. d. Physik **61**, 687 (1897).
[10] Ignatieff, Ann. d. Physik **43**, 1117 (1914).
[11] Barnes and Fulweiler, Phys. Rev. **32**, 618 (1928).

order to maintain the purity of the gas, the traps attached to the tubes are kept immersed in liquid air. The cathode is activated by heating, and by bombardment with helium ions.

The method of taking absorption readings is as follows: shutters B_2 and B_3 (Fig. 1) are closed, and B_1 is open; S_1 is running; and the cathode is at working temperature. The galvanometer deflection upon opening B_2 is J_1, the intensity of the source. B_2 is then closed and the gas in A excited by applying a voltage between the cathode and anode. The deflection when B_2 is then opened is J_2, the intensity of the transmitted light. The percentage absorption is $100(J_1-J_2)/J_1$.

The following is the method of taking the resonance readings: B_1 is open and B_2 and B_3 are closed; and the absorption tube and S_2 are operating. The deflection when B_3 is opened is the resonance reading.

Results

The curves in Fig. 2 show the variation of the percentage absorption for the 2^3S-2^3P line when the conditions in S_1 are varied and those in A re-

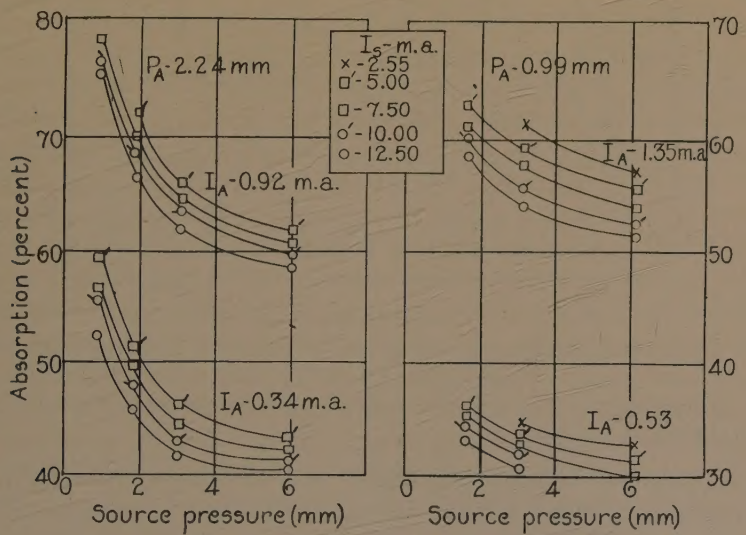

Fig. 2. Absorption 10830A line as a function of source tube conditions. The anode voltage is 29 volts. I_A is the anode box current, P_A the absorption tube pressure, and I_S the current in the source tube (vertical one used).

main fixed. In general, the percentage absorption increases when either the pressure or the current in the source decreases. Similar groups of curves, which are not given here, obtained with other sets of source and absorption tube conditions, show the same effect. It is obvious that if one is to get comparable results for changes in absorbing tube conditions, then the source conditions must remain fixed throughout. The results obtained will depend, of course, on the particular set of fixed conditions chosen for the source.

Fig. 3 depicts the variation of the percentage absorption for the 10830A line when the pressure and current in A are varied. The current to the box

is taken as the abscissa because that current is the one principally responsible for exciting the atoms in the path of the source light. The curves are flatter if the total current is used. The dotted line curve is obtained when the light to be absorbed is taken end on from S_2. This and other curves obtained in the same way show that the absorption is always considerably less then than when light is taken from the vertical capillary of S_1.

The intensity of the 2^1S-2^1P line emitted by the source is so small that absorption measurements can not be made with reasonable accuracy. The indications are, however, that the absorption for this line is small.

The resonance curves for the 10830A line are not shown here. In every case the readings are directly proportional to the percentage absorption, and

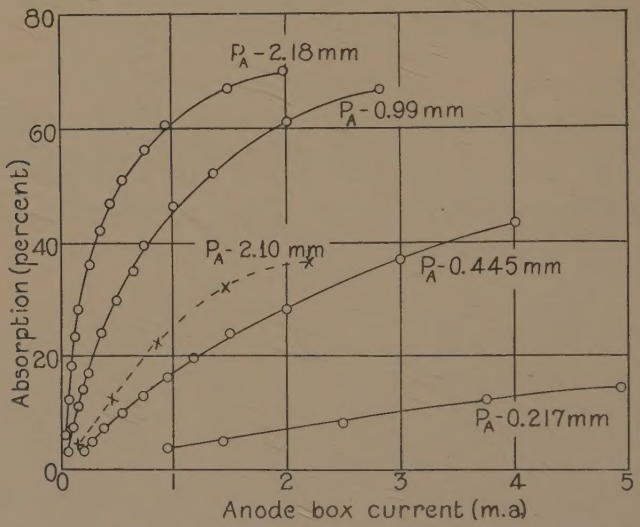

Fig. 3. Absorption of 10830A line as a function of absorption tube conditions. The anode voltage is 29 volts, the source tube current 7.5 milliamperes, and the source tube pressure 6.10 mm. The full line curves are obtained with the vertical capillary source, and the dotted curve with the end on source.

the plot of them can be made to coincide with the corresponding absorption curve by choosing the proper ordinate scale. The largest resonance deflection is 8 cm. The 20582A line shows no resonance.

There is no appreciable variation of absorption with voltage within the range of 25 to 30 volts. The voltage in the range 17 to 22 volts is varied in 0.1 volt steps. If there is any absorption within that range, it is less than 0.1 percent, the smallest detectable amount.

No change of absorption is noticeable when the light from S_1 is polarized and its plane rotated. Such a change might be expected from impact polarization of the atoms in A resulting from collisions with the unidirectional electron stream from the cathode. Some of the desiderata in observing impact polarization are low gas pressures, and at times also, low excitation voltages. To determine polarization under such conditions by the usual methods is difficult because of the low intensities of the emission lines. Absorption measurements with polarized light may be a helpful and more powerful tool in such cases, since then the smallest detectable change will

depend on the intensity of the source and this can be varied at will. The failure to notice any change in absorption in this work may have been caused by insufficient uniformity of the electron stream, and by the presence of an undetermined magnetic field due to the cathode heating current, the earth's field, and nearby iron pipes. This problem of absorption of polarized light will be investigated in the near future with more appropriately designed apparatus.

For fixed conditions in the source and absorption tubes, the percentage absorptions obtained in a series of readings check to within 0.4 percent absorption when the galvanometer deflections range from 10 to 40 cm, which is the case at the higher pressures and currents in S_1. In most cases the elapsed time between the first and check determinations is several days. The errors increase of course as the galvanometer deflections decrease. When the source current is equal to or less than 5 milliamperes and the pressure in S_1 is less than 2 mm, the largest difference between the values obtained with fixed conditions for the percentage absorption is 2 percent absorption.

Interpretation of Results

The low percentage absorption obtained when taking light end on from S_2 can be explained on the basis of the intensity distribution in the emitted line. Some light in the central portion of the line emitted by the atoms in the capillary of S_2, DE, is absorbed by the less strongly excited atoms in the wide portion of the tube, DC. This will not occur in the case of S_1 because the light from it is taken off at right angles to the capillary. Therefore, the line from S_2 will have a larger percentage of its energy in the wings of the frequency-energy distribution curve than will the one from S_1, but conversely for the central portions. The emission line from the absorption tube A is narrower than that from either of the source tubes because both the temperature and pressure are lower. Thus, the fraction of the total light from S_2 which can be absorbed in A is less than that for S_1.

The change in percentage absorption at constant source pressure when the source tube current is varied is due to the resulting temperature change of the excited gas. An increase in current causes a rise in temperature, and therefore, the source line becomes correspondingly broader. The percentage absorption will then decrease because the energy absorbed in A is a smaller fraction of the energy in a wide line than it is of that in a narrow one.

An increase in pressure also causes a broadening of the line. Thus the percentage absorption will also decrease when the current is kept constant and the pressure is increased.

The percentage absorptions represented by the first parts of the curves in Fig. 3 are directly proportional to the anode current I_A. After the percentage absorption has reached a value of 10 percent, the curves are given approximately by the equation $A = S \log I_A + m$. S is a constant which is the same for all the curves, and m, a constant which is different for each. The greatest deviation of this equation from the observed values is about 2 percent absorption. This is somewhat larger than the experimental error.

The author wishes to thank Dr. C. B. Bazzoni for suggesting this problem and for his aid and interest in its solution.